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FINAL REPORT

PROJECT NO. A-448

RESEARCH AND DEVELOPMENT OF A ROTATING DEVICE FOR LABYRINTHINE STIMULATION

By

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and

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FOREWORD

This report contains a summary of the development and design of a rotating chair for use in studying the vestibular responses of humans to angular accelerations. The project was sponsored under the provisions of U. S. Air Force Contract No. AF 41(657)-277 under the technical cognizance of Dr. Robert L. Cramer, Head, Vestibular Laboratory, ENT Branch, School of Aviation Medicine, USAF Aerospace Medical Center, Brooks Air Force Base, Texas.

ACKNOWLEDGEMENTS

The function generator command system was designed and constructed by Mr. Robert S. Johnson, Mr. Ralph D. Loftin, and Mr. Frank Williamson of the Physical Sciences Division, Defense Branch, of the Engineering Experiment Station of the Georgia Institute of Technology. Their significant contribution to the project is greatly appreciated.

The cooperation of all the personnel of the Engineering Experiment Station who contributed to the project is also gratefully acknowledged.

ABSTRACT

A rotating chair capable of being programmed for constant angular accelerations and sinusoidally varying velocities is described. The device provides angular acceleration stimuli to human subjects for studying the response of the labyrinthine system in the inner ear. An electro-hydraulic servo system provides the motive power, and an analog computer function generator provides the controlling command signal.

The device permits the rotating of seated human subjects about a vertical axis through the head at constant angular accelerations from .05 to 160 deg/sec^2 and velocities from 2 to 160 deg/sec. The system includes power and instrument slip rings for transmission of signals to and from the rotating chair. An aluminum enclosure permits complete control of the ambient lighting around the subject. A recording oscillograph permits monitoring and recording of the speed and physiological responses.

I. INTRODUCTION

The flight into space of humans with attendant body rotation and weightlessness has created a need for a greater understanding of the vestibular canals of the inner ear than now exists. The study of the disorientation and physiological responses of humans and animals produced by constant and varying angular accelerations has been pursued for many years. Many data are available concerning the effects due to head movements while rotating at constant velocity. However, fewer data are available on the effects of constant angular acceleration because only a few simulators in existence are capable of producing the required motions.

Ideally, the stimulator would rotate the subject at constant angular acceleration up to a selected terminal velocity with complete absence of vibration and noise. Of course, at accelerations producing significant tangential and centripetal forces, the subject can sense the direction and intensity. Thus, responses at high accelerations must be determined primarily from recorded physiological signals. Development of the labyrinthine stimulator began in May 1959, according to specifications established by Dr. Robert L. Cramer, Head of the Vestibular Laboratory at the USAF School of Aviation Medicine. The stimulator was completed and installed in the Vestibular Laboratory at the School of Aviation Medicine in February 1961. The principal design specifications are outlined below.

The chair should be removable from the platform and capable of repositioning so as to bring the subject's head in coincidence with the axis of rotation regardless of the degree of passive tilting. The back shall allow a total of 40° tilt fore and aft. The chair must be encapsulated to prevent the subject's detection of movement due to air resistance.

A. Slip Rings

At least 25 each of power and instrument slip rings shall be provided.

B. Bearings

The noise and vibration shall not exceed subliminal limits of human detection.

C. Drive

The drive system shall be designed for human loads ranging from 100 to 250 pounds with minimum back lash. Noise and vibration shall not exceed subliminal levels.

D. Program of Rotation

The chair shall be capable of constant angular accelerations ranging from $0.1°/sec^2$ to $160°/sec^2$. The duration of terminal velocity shall range from 0.5 seconds to 30 minutes. Deviations from constant velocity shall not occur at rates exceeding $0.2°/sec^2$. The chair shall be capable of sinusoidal velocity variations up to 160 deg/sec with periods of 4, 20, 40, 80, 160, and 320 seconds.

E. Velocity

Discrete selection of acceleration, deceleration, constant velocity interval, and terminal velocity shall be provided.

F. Noise

Noise should be damped to permit masking by a very moderate level.

II. GENERAL DESCRIPTION OF THE APPARATUS

The labyrinthine stimulator consists of three major components; the rotating chair, the electrohydraulic servo controlled drive system, and the command function generator.

The rotating chair is mounted on the flange of a vertical spindle in a fabricated steel pedestal. The spindle is driven by a rotary hydraulic actuator through a 20:1 ratio double enveloping worm gear reduction. The hydraulic motor is controlled by a variable displacement pump. The pump output is controlled by a two stage four way servo valve, which is controlled in turn by a transistorized servo-amplifier. The command signal is provided by an analog computer function generator. The velocity feedback to the control system is provided by a two phase A.C. tachometer mounted on the hydraulic actuator. Power and communication circuits are supplied to the chair during rotation by a set of 25 slip rings mounted on the spindle shaft. A set of 30 slip rings above the canopy provides for the transmission of low level signals from electrodes and preamplifiers. A nine channel recording oscillograph permits recording of the subject's responses during acceleration and constant velocity rotation.

The hydraulic system, function generator, and recorder are controlled from an operating console which contains all the electrical and electronic circuits. One operator can control the chair and record the subject's responses. The function generator provides for discrete selection of acceleration and velocity in steps of 1/1000 of the total range. This permits accurate reproduction of repetitive programs. Only six periods are available in the sine mode, however, others may be added by a slight modification of the function generator.

III. ROTATING CHAIR AND PEDESTAL

A. Canopy and Chair

Figure 1 shows the rotating chair, pedestal, and hydraulic system during construction. The pedestal side panels have been removed to

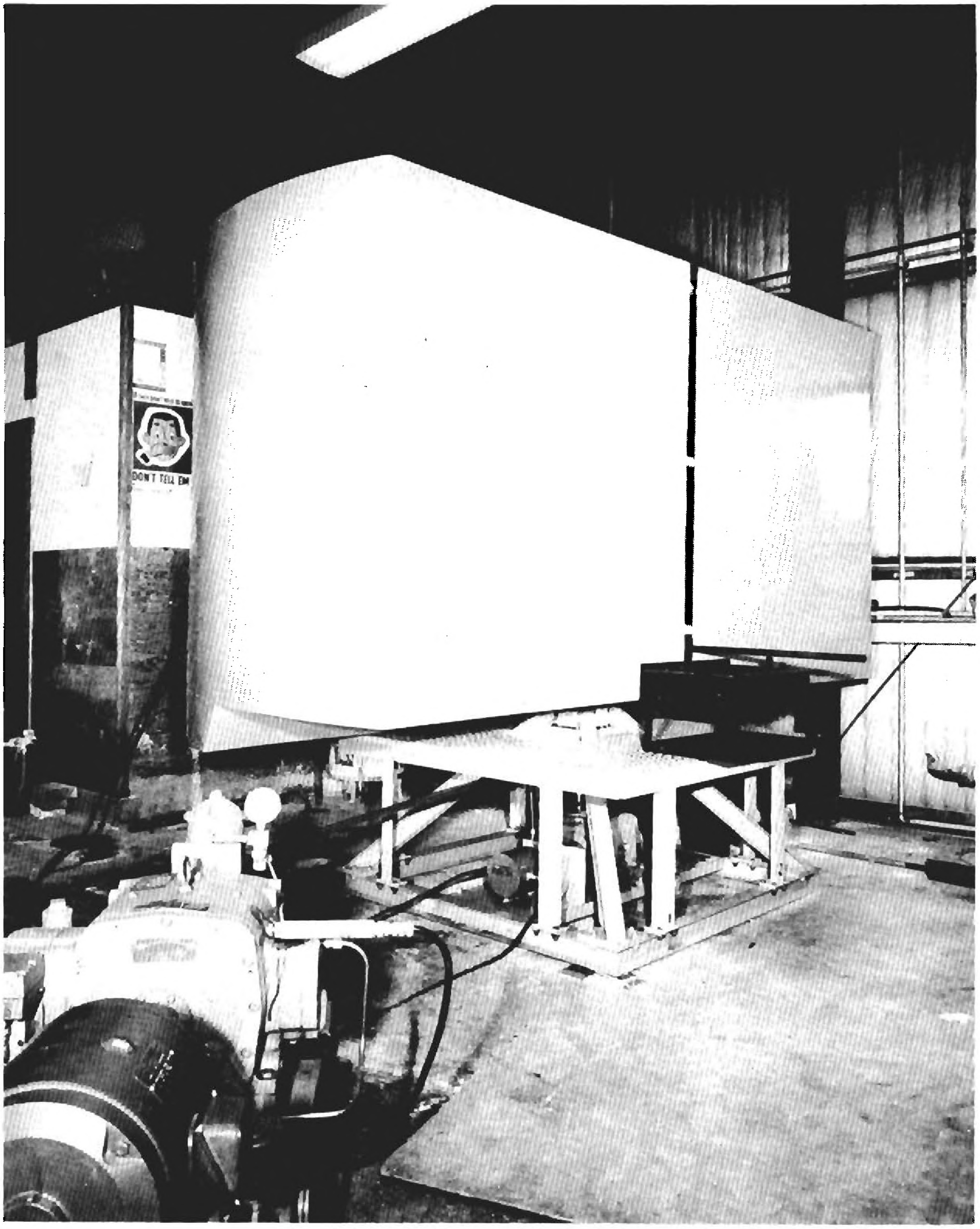

Figure 1. Rotating Chair, Pedestal, and Hydraulic System.

disclose the construction details. Both sides of the clamshell type canopy open to permit access to the subject's chair. A rack outside the canopy will support approximately 75 pounds of preamplifiers and recorders.

Side and top views of the subject's chair without the canopy and cushions are shown on Figures 2 and 3, respectively. The chair is supported by ball bushings mounted on an aluminum channel frame. A standard Ritter trigger type head rest permits passive adjustment of the subject's head with respect to the body. A ball screw adjustment allows a total of 40 degrees of tilt of the chair back, 5 degrees forward of the center of rotation and 35 degrees back. The head support adjustment at the top of the backrest is constrained by two vertical rods to slide up and down on the axis of rotation. The arm rests are hinged to remain parallel to the seat throughout the full range of back tilt. A subject is shown in the chair in Figure 4. Lap and shoulder straps are provided to restrain the subject during high acceleration runs. The instrument slip ring patch panel is mounted above the subject's head and a power slip ring panel is mounted on the frame behind the subject. A rear view of the chair is shown in Figure 5. The sector plate at the top of the backrest provides for $\pm 30^\circ$ head rest adjustment from the vertical. Approximately 4 inches of vertical backrest adjustment is provided by the hand wheel near the bottom of the backrest.

The forward portion of the canopy is fixed. The rear canopy portions close behind the subject and latch against the vertical frame shown in Figure 5. The canopy and chair are secured by bolts to the vertical spindle flange and are removable.

B. Pedestal

Details of the pedestal are shown on Figures 1, 2, 3, and 6. The

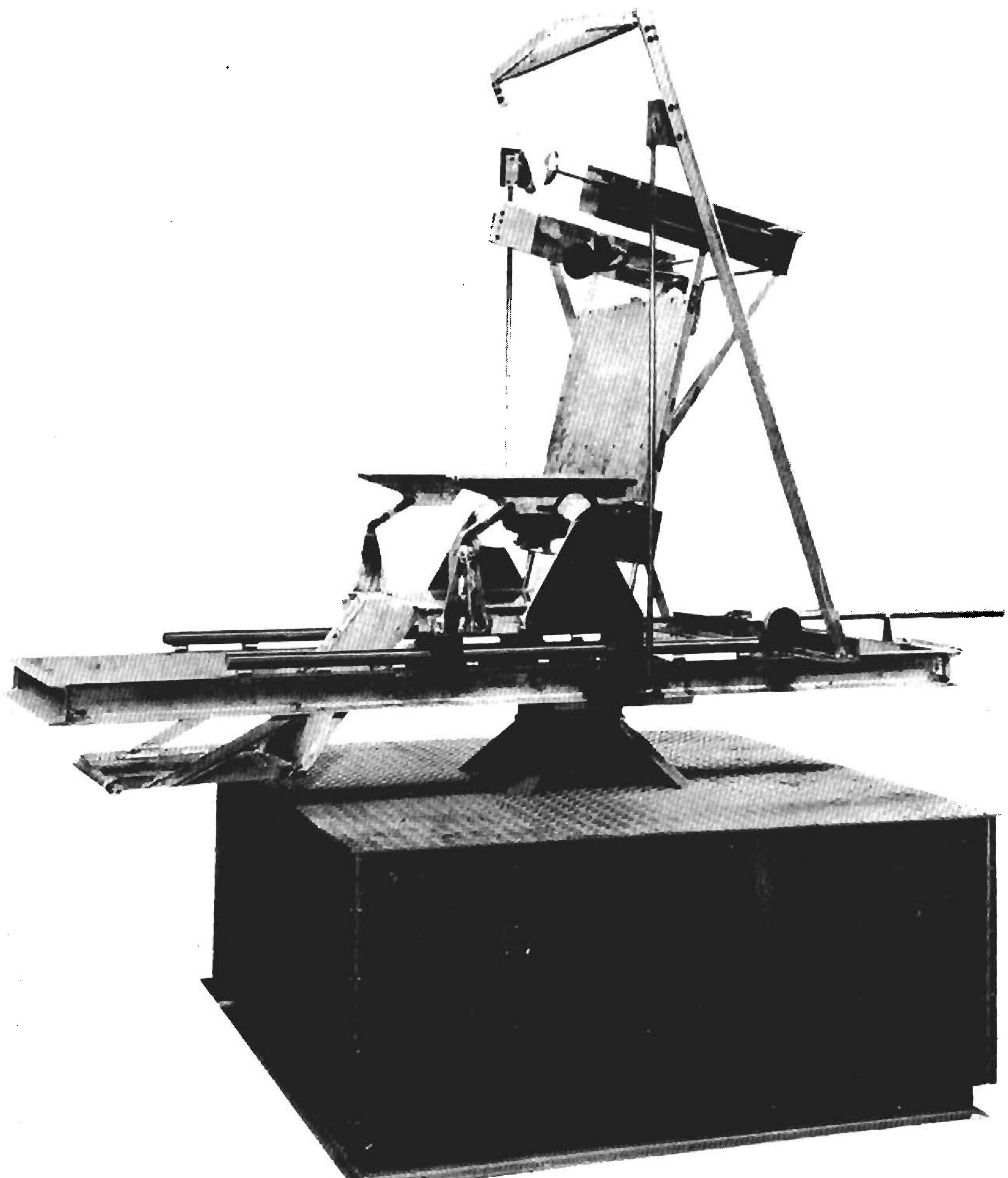

Figure 2. Subject's Chair, Side View.

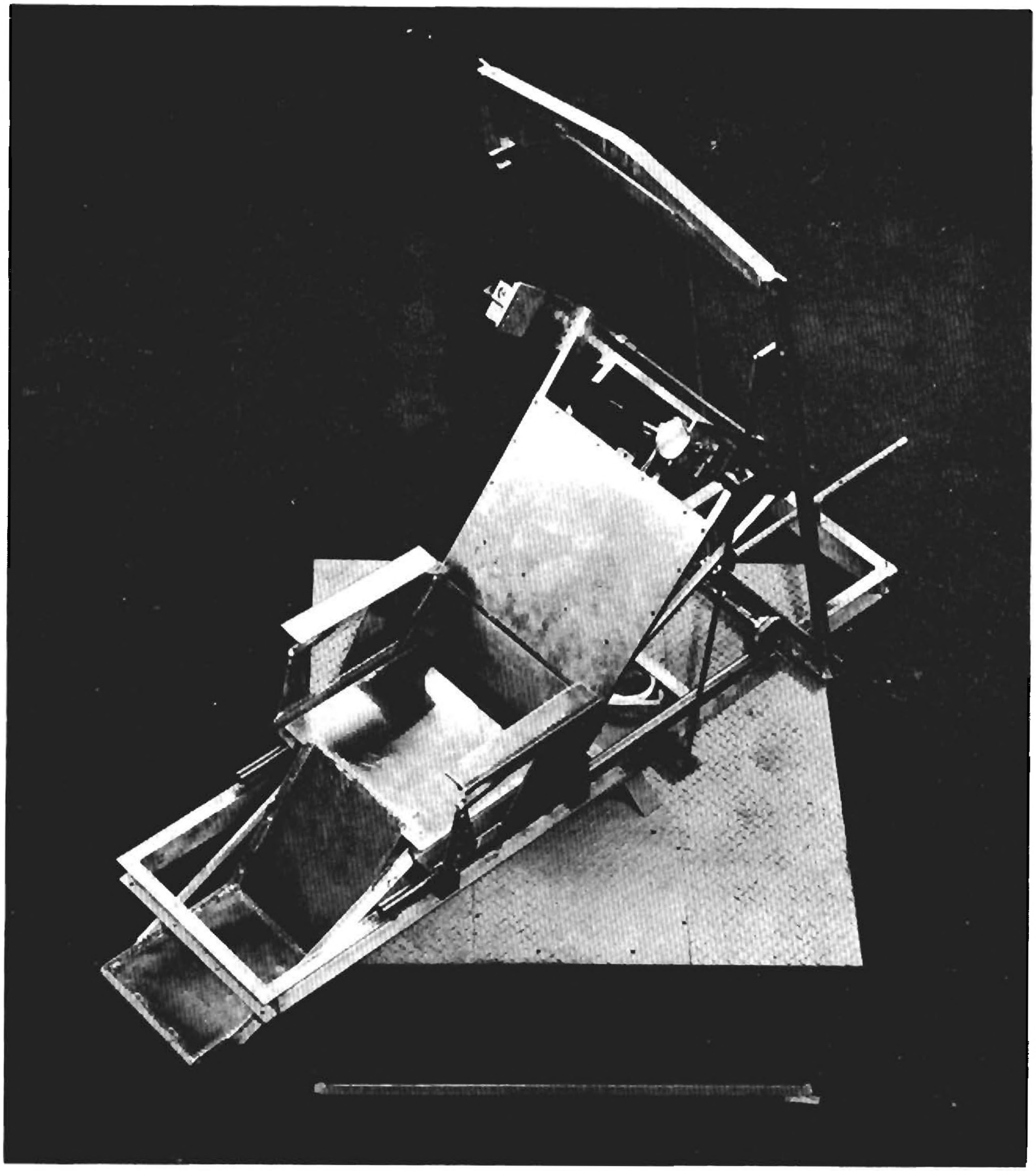

Figure 3. Subject's Chair, Top View.

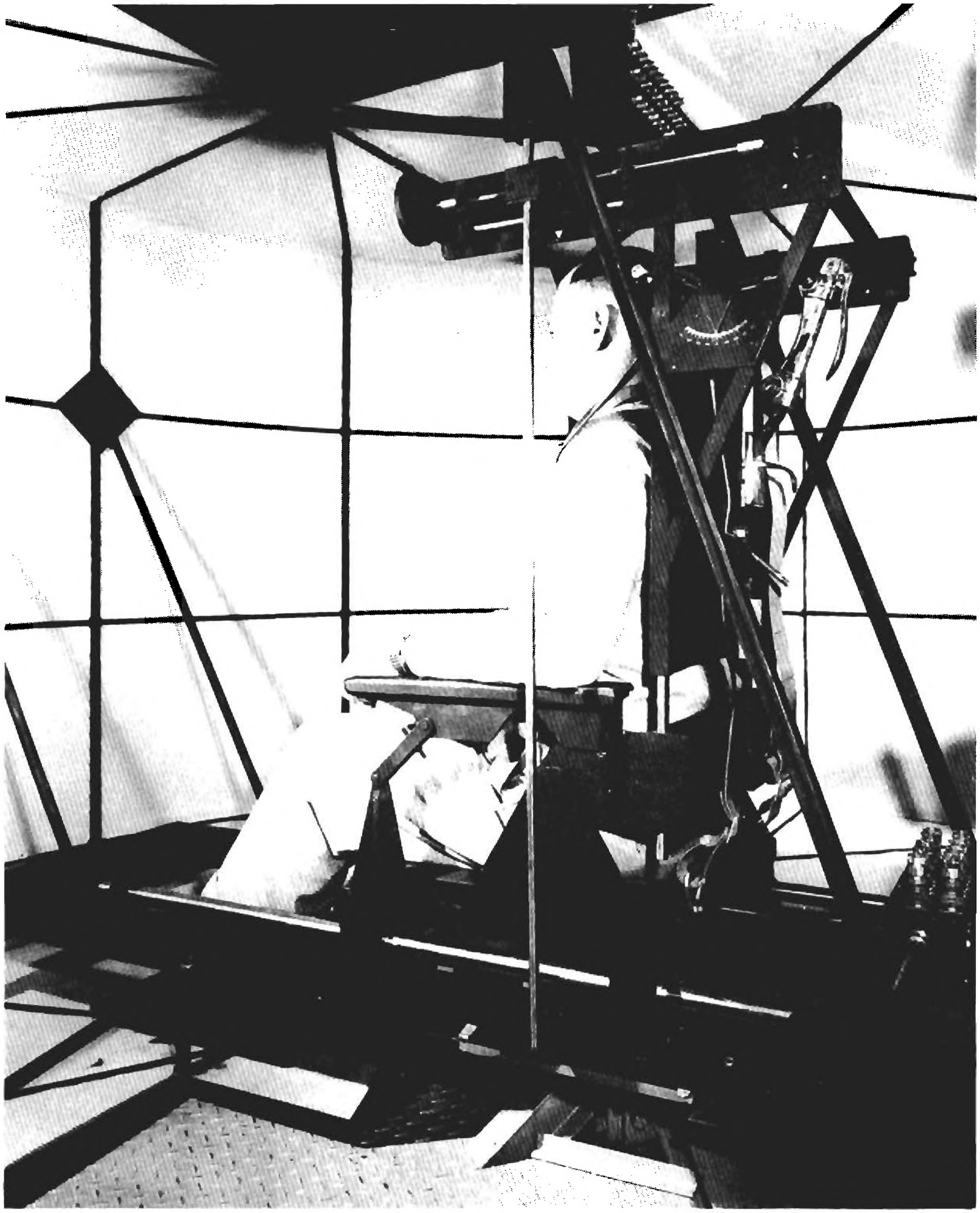

Figure 4. Subject's Chair, Canopy Closed.

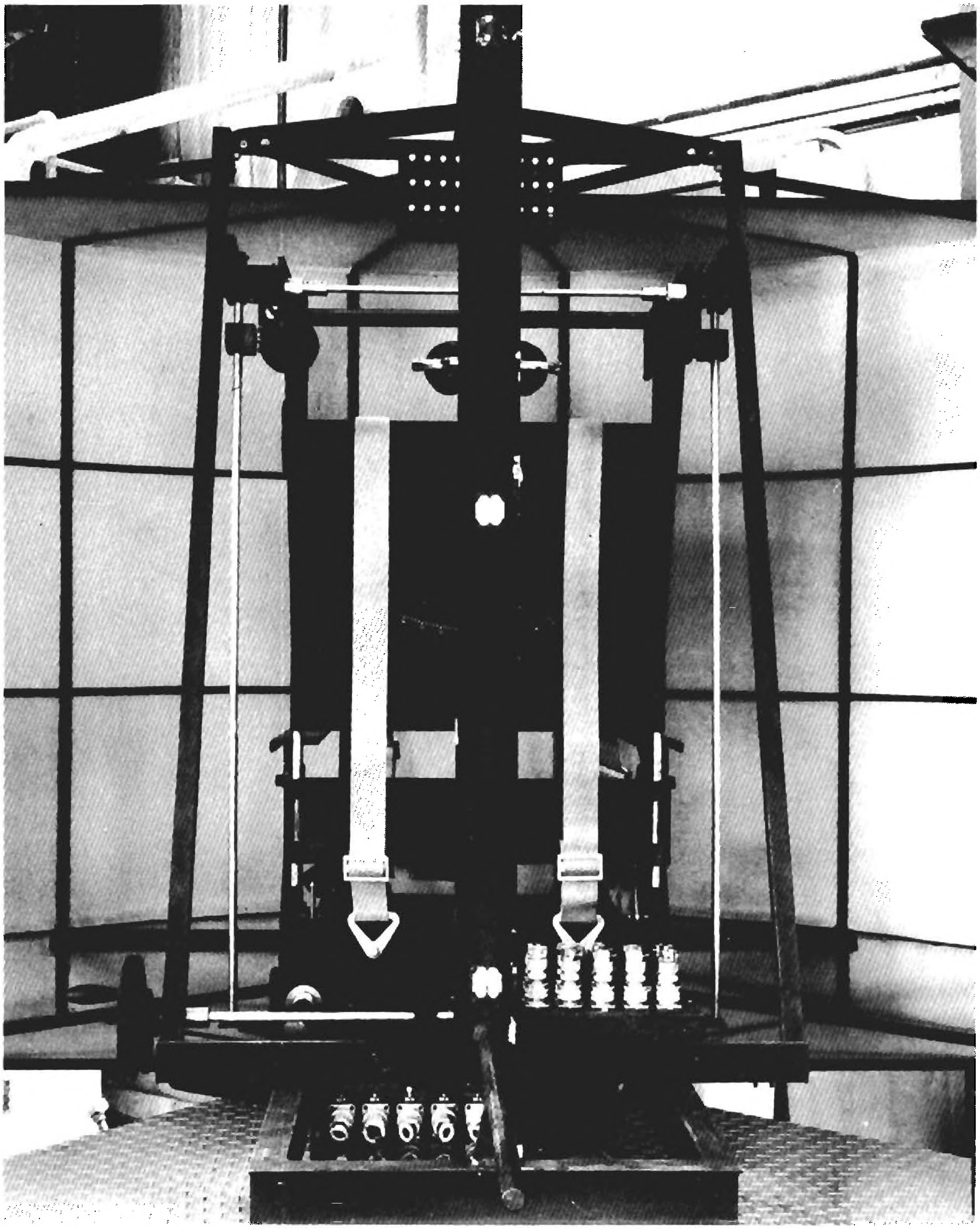

Figure 5. Subject's Chair, Rear.

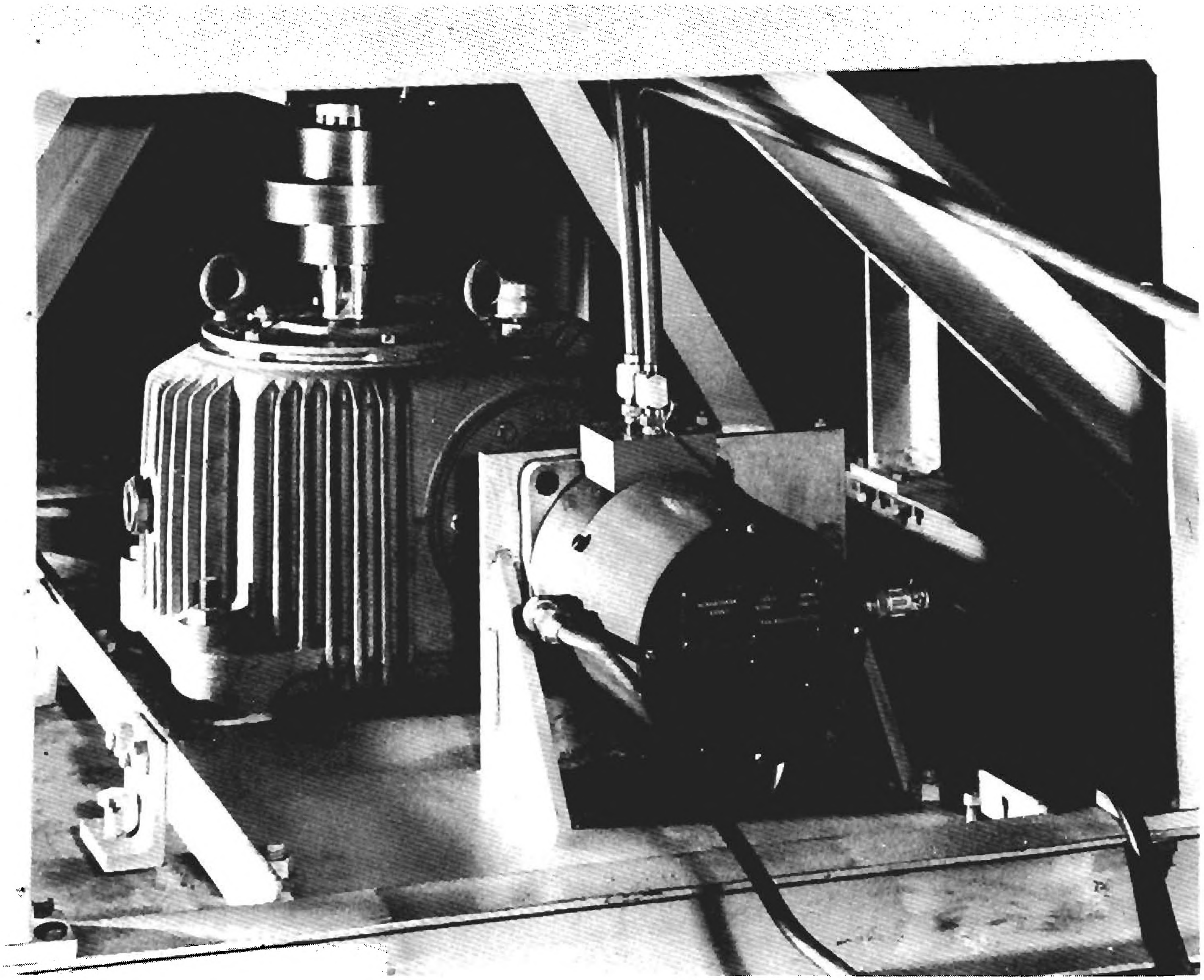

Figure 6. Hydraulic Actuator and Gear Reducer.

structural frame is fabricated from steel I-beams. An aluminum platform is attached to the frame to provide standing space. The spindle shaft is positioned by two preloaded tapered roller bearings. A flange type coupling at the lower end of the shaft, shown in Figure 6, connects the spindle to the gear reducer output shaft. The gear reducer is a 20:1 ratio, double enveloping worm gear, lapped to 0.002 inch maximum backlash. The gear reducer input is flange coupled to the hydraulic actuator, which is mounted on a bracket welded to a base plate.

IV. ELECTROHYDRAULIC SERVO SYSTEM

A. General Description

The electrohydraulic servo systems consists of three major components, i.e., hydraulic power supply, servo amplifier, and hydraulic actuator. The servo system schematic diagram is shown on Figure 7.

B. System Components

1. Transistor Servo Amplifier

The Minneapolis-Honeywell Type XRJ301B2 full wave amplifier is capable of accepting several low power A.C. inputs and amplifying the resultant signal to a higher voltage and power level. In this system the amplifier has three inputs. The command function generator input to terminal 11, the tachometer feedback to terminal 14, and the servo valve feedback to terminal 12 are summed to provide the amplifier input signal.

2. Servo Valve

The servo valve is a Minneapolis-Honeywell Type V7037B1027 4-way valve with a linear variable differential transformer to provide feedback of the valve spool position. The single stage valve has an output flow proportional to the input signal. The valve contains a steel spool and

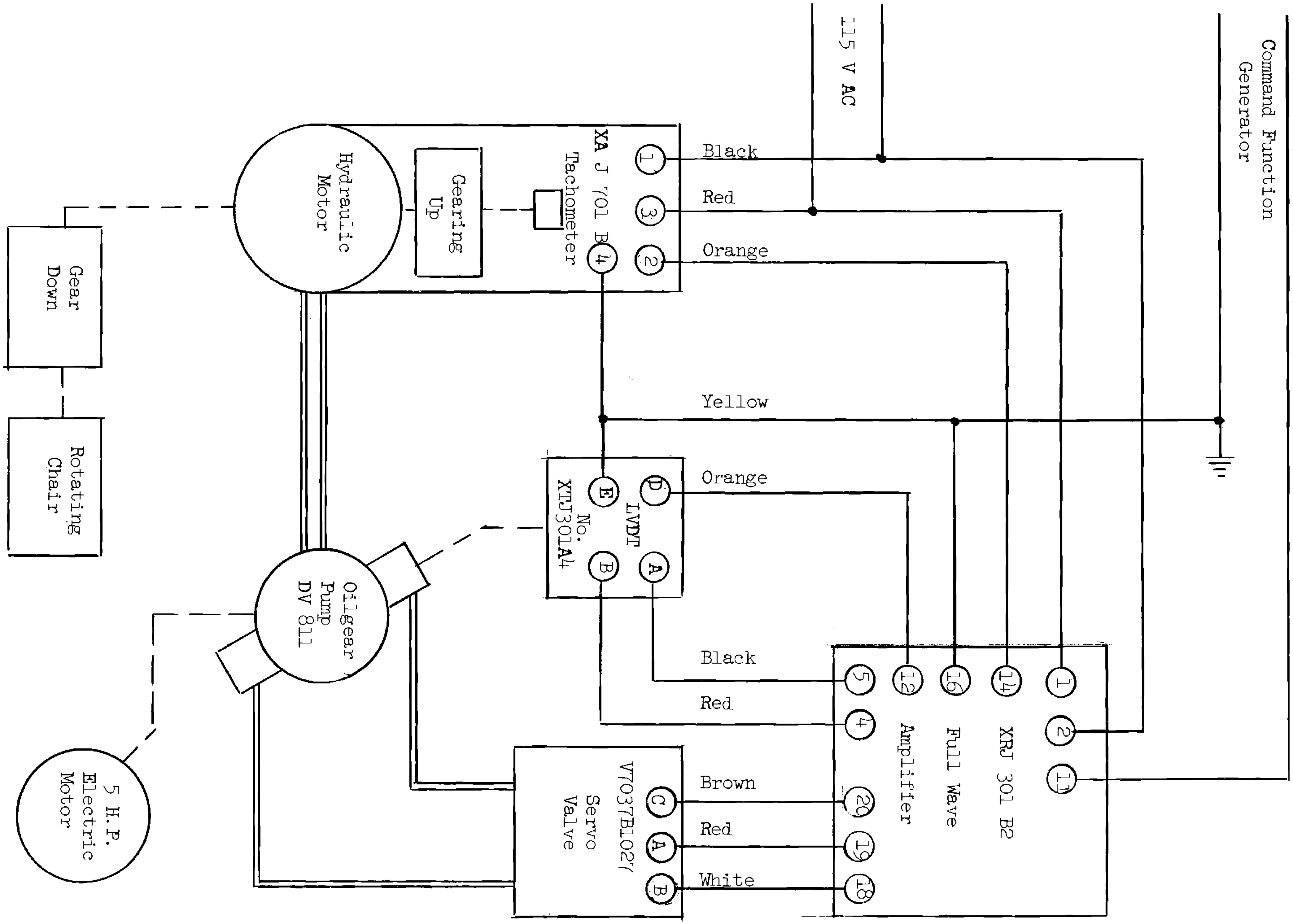

Figure 7. Electrohydraulic Servo System Schematic

sleeve assembly. The spool is positioned in the sleeve by a permanent magnet torque motor. The core of the linear variable differential transformer (LVDT) is rigidly attached to the valve spool, resulting in a feedback transducer that produces an output voltage proportional to spool displacement. This voltage, when used as a feedback around the valve and amplifier, improves the frequency-response of the amplifier-valve loop, and reduces the effect of static friction and hysteresis.

3. Hydraulic Power Supply

The hydraulic power supply consists of an Oilgear Type DY811 hydraulic pump, Oilgear 14 gallon reservoir, and 5 H.P. Reliance 220 Volt A.C. induction motor. The pump has a peak capacity of 13.4 gallons per minute at a pressure of 1100 psia and a speed of 1140 revolutions per minute. The standard DY811 pump was modified by replacing the Oilgear servo control on the pump slide block control piston with the Minneapolis-Honeywell servo valve. The control piston positions the slide block in the pump to provide the desired volume and direction of fluid flow to the hydraulic motor. The LVDT produces an electrical signal proportional to slide block movement. If the slide block voltage is not identical to the command voltage, the servo valve spool is actuated. The movement of the servo valve spool permits fluid to flow to reposition the slide block.

The hydraulic reservoir is a JIC Standard 14 gallon tank and motor base. The 5 horsepower Reliance motor is flange coupled to the pump and electrically controlled from the operating console.

4. Hydraulic Actuator

The Minneapolis-Honeywell Type AJ701 hydraulic actuator consists of a constant displacement roll-vane type motor with a displacement of 2.2 cubic inches per revolution. A drag-cup tachometer is mounted directly on one of the four roll vanes which are geared to the rotor. The tachometer operates at twice the angular velocity of the rotor. The maximum motor output torque of 320 inch-pounds is developed at near-zero speeds. The droop in the torque-speed curve is approximately 10 inch-pounds per 100 rpm. The maximum motor speed is 532 revolutions per minute at the maximum accelerator speed of 26.6 revolutions per minute.

C. Operation

1. Component Set-Up and Adjustment

a. Servo Amplifier. Terminals 1 and 2 of the amplifier are used for the 115 volt A.C. supply. All signals grounds are connected to terminal 16. The amplifier end of the shielded cables to the tachometer, LVDT, and servo valve should be grounded to terminal 16. When the pertinent system wiring is completed, turn on electric power to the amplifier. Do not turn on hydraulic power. With amplifier controls Gain 1 and Gain 2 set at zero (maximum counter-clockwise) check amplifier terminals 18 and 19 or 19 and 20 for a reading of 9 to 11 volts d-c. The voltmeter should have a sensitivity of 1000 ohms per volt or better. This voltage provides a 70-80 milliampere current to the servo valve torque motor to minimize threshold characteristics of the servo valve. The quiescent current of approximately 130 milliamperes is fixed on the Type RJ301B2 amplifier. The BIAS control determines only the magnitude of the dither. If dither is excessive, the excess can be filtered out with 100 mfd capacitors across amplifier terminals 18-19 and 19-20. The dither creates a small oscillatory motion of the valve spool to prevent build-up of very small particles around the valve spool lands when the spool is centered. These particles increase the breakaway friction and cause erratic valve action.

b. Slide Block Linear Variable Differential Transformer (LVDT). The LVDT providing a feedback of the pump slideblock position is connected to amplifier terminals 12 and 16 (ground). The LVDT should be phased to the amplifier as follows:

Connect the ground side of the Y axis input of an oscilloscope to amplifier terminal 16. Connect the scope Y input to terminal 12. Turn on the hydraulic power supply and provide an input to the servo valve with the manual potentiometer or function generator. This will move the LVDT off null and provide an output signal. Adjust amplifier control PHASE 2 until the LVDT output voltage (terminals 12 and 16) is in phase with the line reference voltage as indicated by a diagonal ellipse closed to a minimum on the scope, preferably a straight line. The type XTJ301A4 LVDT used in this system has a primary impedance of 77 ohms. The lagging excitation voltage of the amplifier can be adjusted from 5° lagging to 30° lagging, which is sufficient to bring the secondary voltage of the LVDT in phase with the line voltage. The basic linear variable differential transformer used in the XTJ301A4 unit is manufactured by Schaevitz Engineering, Camden, N. J., as Series 300SS-L.

The output of the LVDT should be at a minimum with the valve spool centered. If it is not, proceed as follows: Apply rated voltage, 6.3 volts, 60 cycles to the LVDT primary (terminals 4 and 5 of the amplifier). Apply a 60 cycle voltage to the horizontal input of an oscilloscope. This should be in phase with the line phase of the amplifier. Connect the vertical input of the oscilloscope across the LVDT secondary windings (pins D and E). The phase control of the amplifier, with a 2 mfd capacitor across the secondary winding, provides an in-phase output when the LVDT core is displaced from center. This is indicated by a diagonal line on the Lissajous pattern of the oscilloscope. When the LVDT core is centered, a horizontal line should exist, with possibly a small amount of quadrature. To adjust the LVDT, loosen the lock nut against the hydraulic pump case and screw the LVDT case in or out as required to minimize the vertical scope deflection. Hold the case in position and tighten the lock nut.

c. Servo Valve. The Model V7037B1027 servo valve is installed on the pump housing. Pins A, B, and C are connected to amplifier terminals 19, 18, and 20, respectively.

Centering the spool is the only adjustment required on the servo valve. If the valve is not centered, the electrical and mechanical nulls may not coincide. This condition is evident if the hydraulic motor rotates without a valve signal input. If it becomes necessary to recenter the valve spool, do as follows: Remove the torque motor cover and valve body end cap. Turn both amplifier gain adjustments to zero. This removes all feedback and command signals. Pressurize the system to operating pressure.

Using the BIAS adjustment on the amplifier, allow sufficient quiescent current to allow dither to be felt in the torque motor armature. Loosen the lock nut fastening the spool push rod to the armature. Center the spool by rotating the spool and push-rod assembly with a screwdriver inserted in the slot in the end of the push-rod. The center position is indicated when the hydraulic motor stops rotating. Tighten the lock nut, while holding the push rod. Replace the end cap and torque motor, first removing any magnetic particles which may have become attached to the armature.

d. Hydraulic Power Supply. No adjustment is required on the hydraulic pump prior to starting. The reservoir should be filled with a medium grade hydraulic oil (Sinclair Duro Oil 300 or equivalent). Precautions should be taken to insure that the pump is not started under load. The pump motor can be "jogged" prior to the full start to insure that the pump is unloaded.

e. Hydraulic Actuator. The tachometer on the actuator should be checked to assure that the output is in phase with the amplifier line voltage. Terminals 1 and 3 should be connected to amplifier terminals 2 and 1, respectively. The tachometer output phase is adjusted by a capacitor across amplifier terminals 14 and 16. A decade capacitor can be used to determine the proper value.

2. System Set-Up and Adjustment

The tachometer feedback indicates the actual velocity as compared to the approximate velocity indication of the servo valve LVDT; therefore, the tachometer feedback dominates the total feedback signal. The proportions of LVDT and tachometer feedback must be determined by trial with the accelerator rotating. The instructions given below result in approximately equal feedbacks.

a. Set the tachometer feedback setting (Gain 2) to zero.

b. Set the LVDT feedback (Gain 1) to zero and turn on hydraulic power to the system.

c. Introduce a command signal from the function generator and gradually increase Gain 1 (LVDT). The accelerator should begin to rotate. If so, then set the Gain 1 potentiometer near the maximum clockwise position. The accelerator speed may be increased to maximum rev./min. by increasing the command signal to the amplifier. Increase the tachometer feedback (turn Gain 2 patentiometer clockwise). The accelerator speed should decrease. If the speed increases, the tachometer is incorrectly phased. Reverse the tachometer excitation leads. The maximum loop gain will be sensed by the servo valve spool. Therefore, for the maximum performance adjustment, observe the LVDT feedback signal with the oscilloscope connected to amplifier terminals 12 and 16. With the LVDT setting at about 3/4 of full setting, increase the tachometer feedback until oscillation occurs, then back off the tachometer feedback until stable operation is obtained. Readjustment of the feedback ratio may be required as the system is "run-in", since operating characteristics of the system components may change.

V. COMMAND FUNCTION GENERATOR

A. Circuit Principles

It is the purpose of the Command Function Generator (CFG) to generate a voltage signal to be fed into the servo amplifier for controlling the angular velocity of the accelerator. Since the servo amplifier is a 60-cycle amplifier, the CFG output must be in the form of an amplitude-modulated 60-cycle signal.

The CFG has 2 modes of operation: the Linear Mode and the Sine Mode. In the Linear Mode the command signal rises linearly from zero to a preset terminal value, holds this terminal value for a preset time interval, then decreases linearly back to zero. The rate at which the preset command voltage rises to the terminal value determines the angular acceleration of the stimulator. The design is such that the rate of deceleration is the same as the acceleration, however, it can be changed during the period at constant velocity if desired.

In the Sine Mode, the output modulation follows the function $(V/2)(1 - \cos wt)$. Thus the velocity starts at zero, rises to a maximum value of V, then decreases back to zero. This biased sinusoidal signal continues periodically for a preset interval.

1. Linear Mode

Figure 8 illustrates the essentials of the Linear Mode operation. The reference voltage is fed into an integrating circuit through a Kelvin-Varley voltage divider which sets the rate at which the integrator output voltage rises. The integrator feeds a 100-volt comparator which is adjusted to energize a relay when the input voltage reaches 100 volts. When the relay is activated, it removes the input to the integrator, thereby causing the integrator output to hold at 100 volts, and starts the electromechanical timer. After a preset number of seconds, the timer removes the positive reference input to the integrator voltage divider and substitutes a negative reference. At the same time, the timer releases the relay and allows the input voltage to be reapplied to the integrator. Due to the reversal in input polarity, the integrator now integrates back down toward zero. When the voltage reaches zero, the zero-volt comparator is energized, which places the integrator in the reset position until the "Start" button is depressed to begin another run. The output of the integrator is also fed into an amplifier and thence into a second Kelvin-Varley voltage divider. The output of this voltage divider is fed into a chopper modulator

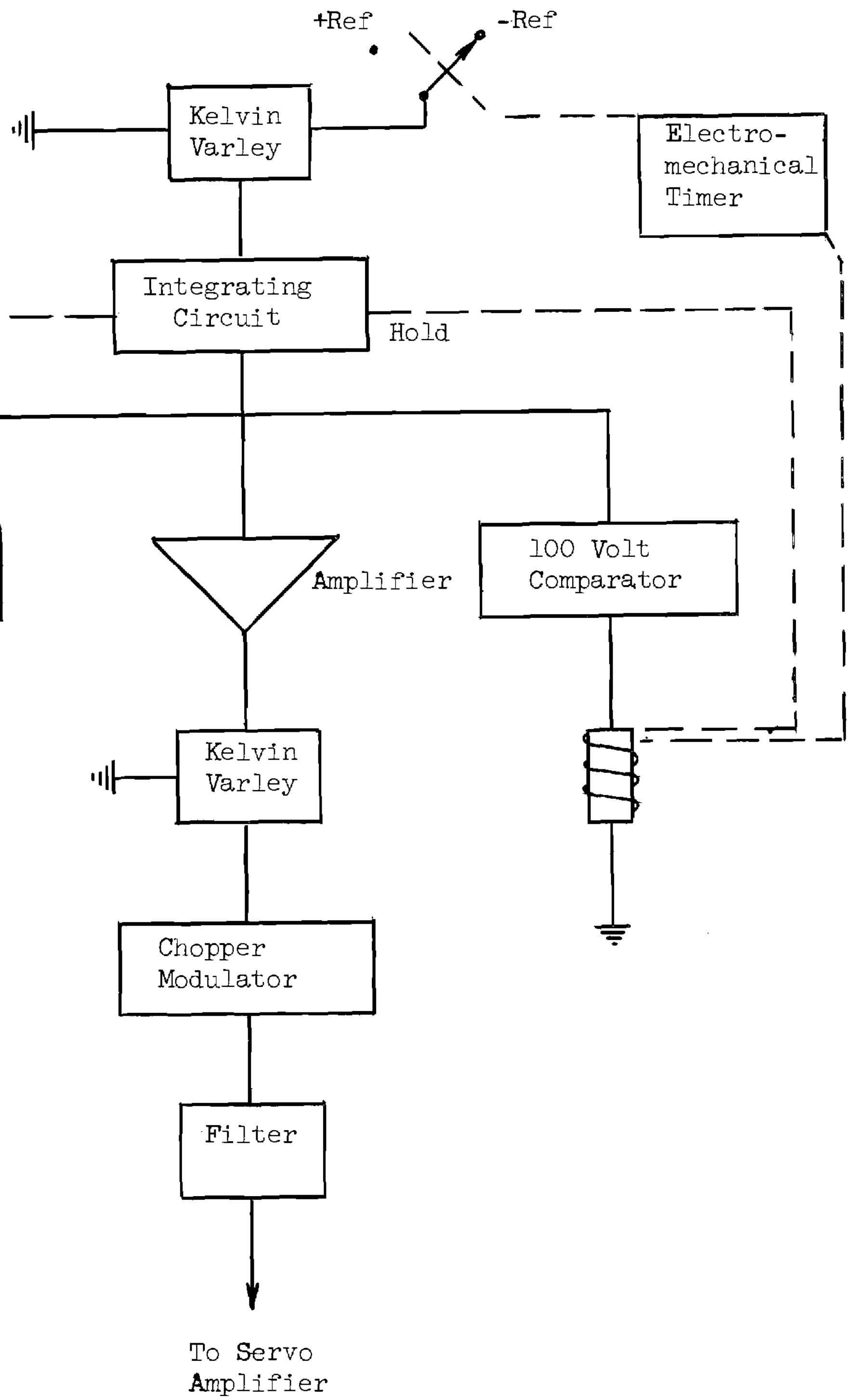

Figure 8. Linear Mode System

which converts the signal into an amplitude-modulated 60-cycle square wave. This square wave is then filtered to provide the 60-cycle sine wave required by the servo system. Note that the second Kelvin-Varley voltage divider also affects the slope of the ramp (terminal velocity); therefore, when adjusting the integrator voltage divider to obtain a desired acceleration rate, the effect of the second divider must be taken into account. The simplest way of doing this is to set the integrator divider to a value corresponding to the quotient of acceleration and terminal velocity.

2. Sine Mode

Figure 9 shows in block diagram form the basic circuitry of the Sine Mode system. The output voltage of the bistable circuit, e_1, is initially 100 volts negative which causes the integrator output to rise linearly in the positive direction. When the integrator voltage, e_o, reaches 100 volts, the bistable circuit changes state and e_1 becomes 100 volts positive. The integrator then reverses direction and begins to integrate negatively. When e_o again reaches zero, the bistable circuit reverts to the original state of 100 volts negative and e_o begins to climb linearly back toward plus 100 volts. Thus, e_o is a triangular waveform varying between 0 and 100 volts. The frequency of this wave is determined by the time constant of the integrator. This time constant is selected by front-panel control to give the desired period of oscillation. The triangular wave is fed into a diode shaping circuit which alters the linear rise and fall into a wave of the desired function, $50(1 - \cos wt)$. The output Kelvin-Varley voltage divider adjusts the amplitude to give the desired peak velocity, and the modulator converts the signal to a modulated 60-cycle wave for driving the servo amplifier.

The electromechanical timer allows the run to proceed for the preset length of time and then resets the integrator. Note that if the number of

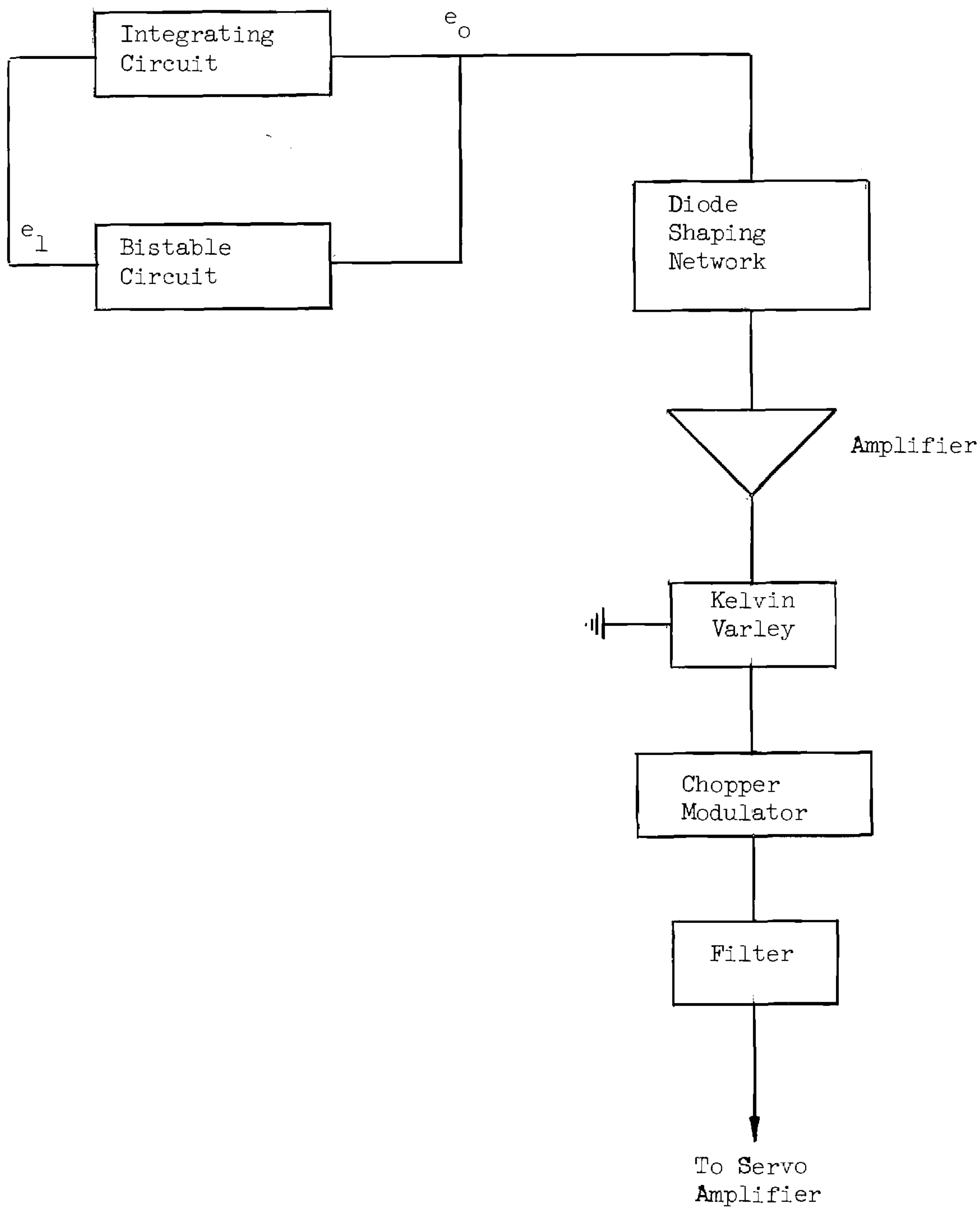

Figure 9. Sine Mode System

second selected for the run does not correspond to an instant when the output signal is zero, i.e., after an integral number of cycles, then the chair will be brought to an abrupt stop. The reset circuit for the integrator includes a protective device to prevent an abrupt stop which would damage the stimulator or injure the subject.

B. Operation

The front panel controls enable the operator to select the mode of operation (linear or sine), the acceleration in the linear mode, the terminal (linear mode) or peak (sine mode) velocity, the sinusoidal period of oscillation, and the length of time at constant velocity (linear mode) or length of run (sine mode). With reference to Figure 10, the following discussion describes the function of each selector and indicator light.

1. Acceleration/Velocity

The lower Kelvin-Varley voltage divider is used to select the rate at which the stimulator attains the terminal velocity in the linear mode of operation. As mentioned in the section on Circuit Principles, this divider cannot be calibrated directly in units of acceleration since the output Kelvin-Varley divider (Velocity) also affects the acceleration. The Acceleration/Velocity control should be set to this quotient of the desired acceleration divided by the terminal velocity. Thus, for an acceleration of 80 degrees/second^2 with a terminal velocity of 160 degrees/second, the setting should be 0.5. This control has no function in the sine mode of operation.

2. Velocity

The Kelvin-Varley voltage divider marked "Velocity" is used to select the terminal velocity in the linear mode and the peak velocity in the sine mode. The dial setting is obtained by dividing the desired terminal velocity by 160 degrees/second. Thus, the setting would be 0500 for 80 degrees/second

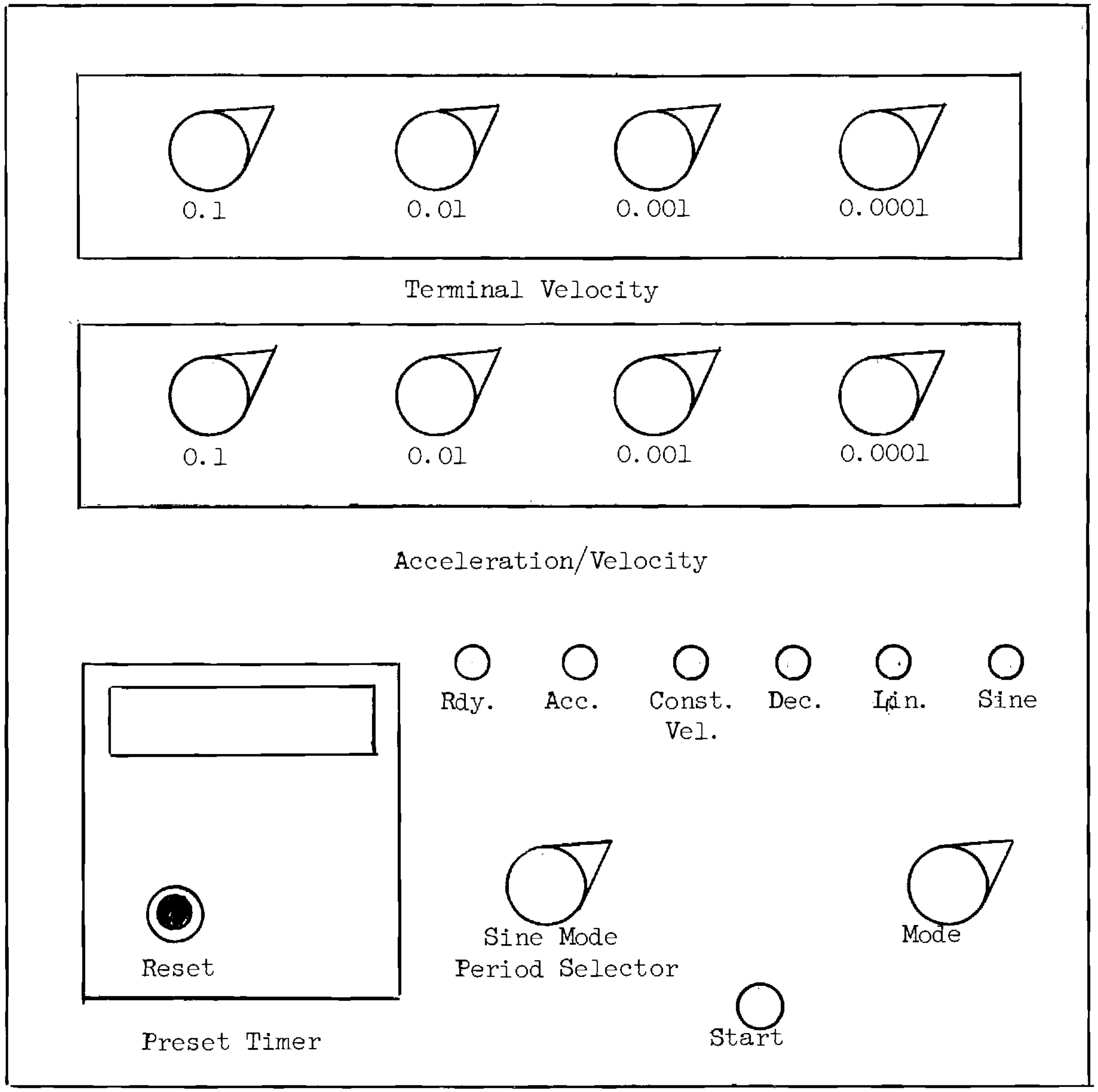

Figure 10. Control Panel

and 1000 for 160 degrees/second.

3. Timer

The electromechanical timer located at the lower left at the control panel is used to set the constant velocity inteval in the linear mode and to set the total length of run in the sine mode. The upper register indicates the preset time and the lower register shows the length of time that the run has progressed. Both registers count in units of 0.1 seconds. After each run and before another run can be initiated, the reset button must be fully depressed and released slowly to release the "B" relays in the CFG and to return the timer to zero. The timer must NEVER be reset until the run is fully completed and the green "Ready" light is lighted.

4. Sine Period

The six-position switch located to the right of the timer is used to select the period of oscillation in the sine mode. The six positions are marked directly in seconds. This switch has no function in the linear mode.

5. Mode Switch

The two-position switch located on the lower right of the control panel is used to select the mode of operation, Linear or Sine. The indicator lights directly above the switch show the current mode.

6. Start

The momentary-contact switch marked "Start" is pressed to initiate a run. This switch is provided with a stiff return spring to minimize the possibility of an accidental start.

7. Indicator Lights

Four lights marked "Ready," "Accel.," "Constant Velocity," and "Decel" are provided to indicate which part of the program is in progress. The

"Ready" light indicates that the program may be initiated. In the linear mode, the "Accel." light indicates that the chair is accelerating toward the preset maximum velocity. In the sine mode, the light indicates only that the program has been initiated. No other lights are lit during the sine mode. The "Constant Velocity" light indicates that the chair has attained the preset maximum velocity and is being held at this velocity.

The "Decel." light indicates that the preset constant velocity interval is over and the chair is decelerating to zero. After the chair has come to a stop, the "Ready" light will again be lighted while the "Decel." light will remain lighted until the timer is reset.

8. Application of Power and Adjustment

The stimulator hydraulic motor must be off during the application of power to the CFG and while adjustments are being made. The front-panel filament switch should be turned on at least 15 minutes before the plate power is applied. Upon application of plate power, the CFG amplifiers will experience a transient condition lasting for several minutes which may activate the interval timer. As soon as the amplifiers have recovered, the timer should be reset.

After a 30-minute MINIMUM warm-up period, the amplifiers may be balanced through use of the panel-mounted meter and switch arrangement located at the rear of the cabinet. Place all the amplifiers in the balance mode by placing the "Amplifier Adjust" switches in the "Balance" (downward) position. Turn the meter range switch to "1 volt" and the amplifier selector switch to "1". Adjust the amplifier balance control on amplifier 1 for an average meter reading of zero. Repeat this procedure for the other 3 amplifiers. Return the meter range switch to "off" and the amplifier mode switches to the "operate" (upward) position.

The remaining voltages which must be checked are available at the test jack on the rear of the chassis according to the position of the selector switch located near the test jack. These voltages should be checked with a high-accuracy high-impedance voltmeter such as a digital voltmeter. The table below lists the voltages which should be observed at the various switch positions.

TABLE I. TEST VOLTAGES

Switch Position	Correct Voltage	Adjustment	Procedure
1	- 200 v.	Donner Power Supply	Read directly
2	+ 200 v.	Donner Power Supply	Read directly
3	- 100 v.	R-56	See Note 1
4	- 97 v.	R-75	Read directly
5	+ 100 v. - 100 v.	R-72 R-62	See Note 2
6	+ 100 v. - 10 v.	R-67 No adjustment	See Note 3
7	Diode Network Input	See ADJUSTMENT AND CALIBRATION OF THE DIODE SHAPING NETWORK	
8	Diode Network Output		

Note 1: Place the CFG in the linear mode and the "Acceleration/Velocity" control to zero. Depress the "Start" button to read voltage. After the voltage has been read and adjusted, press the "Manual Stop" button on the rear of the chassis.

Note 2: Place the CFG in the sine mode with the "Sine Mode Period Selector" switch set to "40 sec.". Set in 200 seconds on the timer and depress the "start" switch. The voltage to be read will start at -100 volts and will switch to +100 volts after 20 seconds. The voltage will continue to alternate between plus and minus one hundred volts every twenty seconds until the program is completed or until the "Manual Stop" button is depressed.

Note 3: Set the CFG as in Note 2. The voltage will alternate between "100 volts and a small negative value which is not critical and needs no adjustment.

C. Adjustment and Calibration of the Diode Shaping Network

If observation of the diode network waveform (available at the "D.F.G. Output" jack on the rear of the chassis) should indicate that the shaping network requires adjustment, it is recommended that the entire network be readjusted in order to reduce the possibility of control interaction from a single adjustment.

Place the CFG in the Sine Mode and set the "Terminal Velocity" control to zero. Place the "D.F.G. Input" switch (located on the rear of the chassis) in the "External" or downward position. Connect a variable D.C. Voltage supply to the "External Input" jack located adjacent to the "D.F.G. Input" toggle switch. This D.C. supply must have a low output impedance and a variable output from zero to 100 volts with a resolution of at least 100 millivolts. A Lambda Model 71 supply was used for the original calibration. A D.C. voltmeter capable of reading from zero to 100 volts with an accuracy and resolution of 100 millivolts and possessing an input impedance of no less than two megohms will be needed to monitor both input and output voltages. A digital voltmeter is ideal for this purpose.

Turn R-33, R-36, R-39, R-42, R-45, R-48, R-51, and R-54 to their maximum counter-clockwise positions. These potentiometers are locking types and it may be necessary to release the locking nut before the adjustments can be made. Utmost care should be taken to insure that the potentiometer is not turned on the chassis while the locking nuts are released or tightened. The wiring to the potentiometer may be broken if the potentiometer is twisted.

(1) Apply +50.0 volts at the "External Input" jack and adjust R-80 until the output is 25.0 volts.

(2) Apply 34.8 volts and advance R-42 clockwise until the output voltage just begins to change. The output should be 17.4 volts.

(3) Apply 25.1 volts and adjust R-31 until the output reads 13.3 volts. Advance R-39 clockwise until the output voltage just begins to change.

(4) Apply 16.6 volts and adjust R-27 until the output is 10.7 volts. Advance R-36 until the output just begins to change.

(5) Apply 8.7 volts and adjust R-23 until the output is 9.37 volts. Advance R-33 until the output just begins to change.

(6) Apply zero volts and adjust R-19 until the output is 8.5 volts.

(7) Apply 65.2 volts and advance R-45 until the output just begins to change. The output should be 32.6 volts.

(8) Apply 74.9 volts and adjust R-29 until the output is 36.7 volts. Advance R-48 until the output just begins to change.

(9) Apply 83.4 volts and adjust R-25 until the output is 39.2 volts. Advance R-51 until the output just begins to change.

(10) Apply 91.3 volts and adjust R-21 until the output is 40.9 volts. Advance R-54 until the output just begins to change.

(11) Apply 100.0 volts and adjust R-17 until the output is 41.5 volts.

Repeat steps 1 through 11 for a finer adjustment. Return the "D.F.G. Input" toggle switch to the "Interval" position.

VI. MAINTENANCE INSTRUCTIONS

A. Rotating Assembly

The backrest height adjustment screw and the back tilt adjustment screw should be oiled with machine oil every 3 months. The Cone-Drive gear reducer should be drained every six months and refilled with AGMA 8A Compounded Oil (cylinder oil). One gallon of oil is required. The two vertical spindle bearings on the pedestal and the upper Cone-Drive bearing should be greased through the Zerk fittings every 3 months. Two or three shots with a grease gun should be sufficient. Use a lime or soda base grease of medium (No. 2 grade) to medium soft consistency (No. 1 grade).

B. Hydraulic System

All bolts and machine screws on the hydraulic pump should be checked for tightness once a week if the unit is operated daily. Vibration may cause these fastenings to loosen, allowing hydraulic fluid to escape from the pressurized system. The pipe fittings on both ends of the actuator pressure lines should be checked frequently for tightness. The filter pressure gage on the hydraulic pump should be examined during each day's operation. When the filter pressure rises to the "REPLACE" section of the dial, the filter should be replaced. A spare filter should be kept on hand; however, under favorable operating conditions in a clean atmosphere, replacement will be infrequent.

Should it become necessary to remove the hydraulic lines, extreme care should be taken to avoid getting dust or dirt particles into the open ends. Clean pipe caps should be prepared for installation on the end fittings as they are removed. Any oil added to the system should be filtered through a 200-mesh screen. The reservoir should be drained and refilled every 12 months with Socony Mobil D.T.E. Oil, Medium, or equivalent.

VII. RESULTS

The labyrinthine stimulator was installed in the Vestibular Laboratory at the School of Aviation Medicine of the USAF Serospace Medical Center. The stimulator was designed so that it could be disassembled and moved through a standard door frame for installation.

The minimum angular acceleration of the stimulator is less than 0.05 degrees/sec^2. The minimum smooth angular velocity is approximately 2 degrees/second. The stimulator is capable of a maximum angular velocity of about 60 revolutions per minute, although the present function generator settings are based on a maximum velocity of 160 degrees per second (26.6 rev/min).

Some non-linearity in the function generator output was due to an iron core inductor in the 60 cycle output shaping filter. The filter was replaced with a tunable transistorized filter. The filter also removed some perceptible switching transients at the transition points in the constant angular acceleration program. Some roughness was evident in the Cone-Drive gear reducer after installation. If the roughness is not reduced after a reasonable "run-in," some rework of the worm gear set may be required.

Program reproducibility is excellent due to the use of precision voltage dividers for discrete program selection. During laboratory operation of the device the capacitor discharge circuit in the function generator permits emergency stopping of a program from any speed without injury to the subject. Any future modification of the stimulator would include a complete check out system on a console panel, including oscilloscopes for monitoring the output of the command function generator and the feedback signals.

All original detail design and stress analysis calculations are on file in the Mechanical Sciences Division, Engineering Experiment Station, Georgia Institute of Technology.

Respectfully submitted:

Winston C. Boteler, Project Director

Approved:

Released by:

Thomas W. Jackson, Chief
Mechanical Sciences Division

R. E. Stiemke, Director

APPENDIX

DRAWING LIST
LABYRINTHINE STIMULATOR

Drawing No.	
A-448-000	Master Assembly
A-448-001	Master Assembly, Labyrinthine Stimulator (Canopy Removed)
A-448-100A	Chair Assembly
A-448-101	Chair Positioning Device, Back Adjustment
A-448-102	Lateral Chair Adjustment Sub-Assembly, Left Side
A-448-103	Chair Bottom Frame Assembly
A-448-104	Lateral Adjustment Assembly, Plate Layout and Assembly
A-448-105	Chair Details
A-448-106	Chair Details
A-448-107	Chair Back Frame Assembly
A-448-108	Lateral Chair Adjustment Brace
A-448-109	Chair Details
A-448-110	Chair Details
A-448-111	Chair Details
A-448-112	Chair Details
A-448-113	Head Rest Mount, Details and Assembly
A-448-200	Canopy Frame Assembly
A-448-201	Canopy Frame Details
A-448-202	Canopy Frame Details
A-448-203	Canopy Frame Details
A-448-204	Canopy Skin Details

A-448-300	Beam and Chair Support Assembly
A-448-301	Beam Sub-Assembly
A-448-302	Beam and Chair Support Details
A-448-303	Miscellaneous Beam Details
A-488-400	Main Shaft and Bearing Housing Layout and Assembly
A-448-401	Details: Drive Coupling and Slip Ring Bushing
A-448-402	Drive Details: Shaft, Spindle Plate, Bearing Housing
A-448-403	Spindle Shaft and Plate Assembly
A-448-500	Base Assembly
A-448-501	Bearing Housing Support Assembly
A-448-502	Mount Assembly
A-448-503	Details Bearing Housing Support
A-448-504	Mount Details
A-448-505	Platform Assembly
A-448-506	Platform Details
A-448-600	Electrical and Instrument Diagrams and Details for Chair Assembly
A-448-601	Slip Ring Brush Holder and Cover, Assembly and Details
A-448-602	Tachometer and Position Indication Drive
A-448-603	Function Generator Schematic
A-448-604	Wiring Diagrams for the Control Console

VII. PARTS LIST

A. Rotating Assembly

Part No.	Description	Source	Price
A448-100-1	Headrest, Ritter Model No. B163	Peerless Appliance Co. 126 11th Ave. New York, N. Y.	$65.00
A448-000	Simmons Link Lock Fasteners w/std. keeper plates	Simmons Fastener Corp. N. Broadway Albany 1, N. Y.	.49
A448-100-6	Ball Bushing, $1\frac{1}{4}$" Thomson OPN Type 203242	Thomson Industries Co. 1029 Plandome Rd. Manhasset, N. Y.	2.45
A448-102-2	Positioning Control, Part No. PR190-F-137	Reid Controls, Inc. 2021 N. Lincoln St. Burbank, Calif.	8.86
A448-102-2	Positioning Control No. PR19L-H-T37	Reid Controls, Inc. 2021 N. Lincoln St. Burbank, Calif.	8.86
A448-102-12	Angle gear, Unit No. R-300	Airborne Accessories Co. Hillside, N. J.	23.50
A448-102-15	Bearing, Barden No. 38SS	Barden Bearing Co. Danbury, Conn.	5.91
A448-102-19	Screw, Roton Type NP-33S12F with nut, 15-3/8" long	Anderson Co. Gary 40, Ind.	14.09
A448-102-19	Screw, Roton Type NP-33S12F with nut, 14-3/8" long	Anderson Co. Gary 40, Ind.	13.94
A448-102-19	#NP-33S12 Roton Bearing Screw Assembly	Anderson Co. Gary 40, Ind.	11.14
A448-102-25	Cam Follower, McGill "Camrol" No. CF 3/4	McGill Mfg. Co. Valparaso, Ind.	2.22
A448-102-29	Oil Seal, $\frac{1}{2}$", Part No. 099G16	Chicago Rawhide Mfg. Co. Chicago, Ill.	.38
A448-200-54 -55 -56	Rotron Muffin Filter Fan	Rotron Mfg. Co. Woodstock, N. Y.	15.85

Part. No.	Description	Source	Price
	Seat Belt, No. M7500M13-50 No. 2009 Gray	Air Associates, Inc. Atlanta, Ga.	$7.50
	End Fittings, Seat Belt Part No. M2500M3	Air Associates, Inc.	.47
	Shoulder Harness, Type M7700M2, No. 2009 Gray	Air Associates, Inc.	11.20
	Velcro Closure, 1" wide	Velcro Corp. 681 Fifth Ave. New York, N. Y.	1.00/yd
	Federal #55 RF Ball Bearing, $\frac{1}{2}$" bore, 1-1/8" OD w/retainers and 1 shield	Federal Bearing Co. Poughkeepsie, N. Y.	1.56
A448-300-2	Shaft, 60 Case, Hardened and Ground, AISI Type 1060C Steel, Rockwell 58-63C, Class L, $1\frac{1}{4}$" dia x $44\frac{1}{2}$" long	Thomson Industries Co. 1029 Plandome Rd. Manhasset, N. Y.	31.30
A448-303	Gear, Steel Miter Part No. L112Y	Boston Gear Co.	2.54
A448-303	Bearing Screw, Roton Type CT-42S12	Anderson Co. Gary 40, Ind.	14.68
A448-303-18 -19	Trilok Spacer Fabric, Type 6004-1-1-148	U.S. Rubber Co. 1230 Ave. of Americas New York, N. Y.	6.72/yd

B. Pedestal

Part No.	Description	Source	Price
A448-001-5	Cone-Drive right angle speed reducer, Model HV-7400C-AK, center distance 4", ratio 20:1, 0.002 minimum backlash	Cone-Drive Gear Co. Detroit, Michigan	$389.00

Part No.	Description	Source	Price
A448-400-5	Bearing, Tapered roller Series L713000, Type TS, Cone No. L713049, Cup No. L713010, Bore 2.750" Type "00" Super precision	Timken Roller Bearing Co.	$45.11
A448-400-10	Slip ring assembly Part No. AJ8005-26	Breeze Corp., Inc. 700 Liberty Ave. Union, N. J.	275.00
A448-600-5	Brush Block, Part No. AC262-30	Poly-Scientific Corp. Blacksburg, Va.	69.36
A448-600-5	Slip ring, Part No. AC263-30	Poly-Scientific Corp. Blacksburg, Va.	104.85
A448-602	No. 18XL037 Timing Belt Pulley	Morse Chain Co. Ithaca, N. Y.	1.75
A448-602	No. 60XL037 Timing Belt Pulley	Morse Chain Co. Ithaca, N. Y.	1.75
A448-602	No. 260XL037 Timing Belt Pulley	Morse Chain Co. Ithaca, N. Y.	1.75
A448-602	No. 10XL037 Timing Belt Pulley	Morse Chain Co. Ithaca, N. Y.	1.06

C. Electrohydraulic Drive System

Part No.	Description	Source	Price
A448-001-6	Electrohydraulic Servo System, consisting of the following:	Minneapolis-Honeywell 2747 4th Ave., South Minneapolis 8, Minn.	$7395.00
A448-604	(A) No. XAJ701B2 Hydraulic Motor Package		499.00
	(B) No. XRJ301B2, Proportional Servo Amplifier, Full Wave		315.00
	(C) No. SB80A1003 Transducer (± 0.250" LVDT Round)		173.00

Part No.	Description	Source	Price
	(D) V7037B1027, 4-Way Servo Valve (1GPM) w/LVDT		$472.50
	(E) Oilgear Modified DY811 Hydraulic Pump	Oil Gear Co. 1571 W. Pierce St. Milwaukee, Wis.	not available
	(F) 14 Gallon JIC Motor Base	Oil Gear Co. 1571 W. Pierce St. Milwaukee, Wis.	not available
	(G) Reliance 5 HP 220 V, 3 Phase, 60 cps Induction Motor	Reliance Electric & Engineering Co. 24701 Euclid Ave. Cleveland 17, Ohio	not available

D. Function Generator

Part No.	Description	Source	Price
Console	Counter, Preselection, 10 impulses per second, Model No. TIZ5PIE, 115 volt, 60 cycles, AC counting coil	Sodeco-Geneve 45 W. 45th St. New York, N. Y.	$102.50
Console	Transmitter, Pulse, 36,000 pulses/hr., 115 volt, 60 cycles AC, Model No. TK2W1 360001/h	Sodeco-Geneve 45 W. 45th St. New York, N. Y.	67.50
Console	Power Supply, 28 volt DC, 2 amp 2.5 volt ripple, Unregulated Dressen-Barnes Model No. 21-101	Dressen-Barnes Corp. Pasadena, Calif.	37.00
Console	Decade Voltage Divider Type 1454 A-H	General Radio Co. Silver Spring, Md.	145.00
Console	DC-AC Chopper, 60 cps 6-3 V, AC No. 012	Stevens-Arnold Inc. 22 Elkins St. S. Boston, Mass.	39.60
Console	Dialco Pilot Light No. 810B-431	Dialight Corp. Brooklyn, N. Y.	.21
Console	G.E. Pilot Light No. 1820	General Electric Co. Cleveland 12, Ohio	.209

Part No.	Description	Source	Price
Console	Bud Cabinet, No. CU728	Bud Radio, Inc. Cleveland, Ohio	1.22
Pedestal	D. C Tachometer, Type BYLM 40 Volts/1000 rev/min	Barber-Coleman Co. 1300 Rock St. Rockford, Ill.	45.00
Console	No. 31-001 Amphenol Connector	Amphenol Chicago 50, Ill.	.73
Console	No. 31-002 Amphenol Con- nector	Amphenol Chicago 50, Ill.	.69
Console	No. 31-001 BNC Amphenol Connector	Amphenol Chicago 50, Ill.	1.05
Console	No. 31-002 BNC Amphenol Connector	Amphenol Chicago 50, Ill.	.93
Console	No. 327P6 500-0-500 µA Triplett	Triplett Electrical Co. Bluffton, O.	11.00
Console	No. JBT Model 31 EX 10,000 hour timer	JBT Industries 113 Hamilton St. New Haven 8, Conn.	15.95
Console	No. AN-3102A-28-11S Amphenol	Amphenol Chicago 50, Ill.	2.83
Console	No. AN-3106A-28-11P Amphenol	Amphenol Chicago 50, Ill.	3.47
Console	Bourns Trimmer Poten- tiometer, 100 K ohms 2 watts	Bourns, Inc. Riverside, Calif.	2.25
Console	Bourns Trimmer Poten- tiometer, 100 ohms .25 watts	Bourns, Inc. Riverside, Calif.	2.50
Console	Bourns Trimmer Poten- tiometer, 500 K ohms .2 watts	Bourns, Inc. Riverside, Calif.	2.50
Console	Stancor P8150 transformer 117/12.6 ct, .3 amps, 60 cps	Stancor Electronic 3501 W. Addison Chicago 18, Ill.	3.40
Console	Mallory No. 1311L Rotary Selector Switch 2 pole, 11 position 1 fixed stop, 1 adjustable stop	P. R. Mallory, Inc. 3029 E. Washington Indianapolis, Ind.	1.74

Part No.	Description	Source	Price
Console	Relay - No. CS 120AC 4C 115 V, 60 cps, 4 pdt, .03 sec. operating time, Release time .010 sec.	Potter Brumfield	8.10
R-2	Resistor 13.0 Meg. ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.72
R-4	Resistor 7.0 Meg. ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.72
R-6	Resistor 3.6 Meg. ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.89
R-8	Resistor 20.0 Meg. ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.72
R-10	Resistor 9.0 Meg. ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.72
R-12	Resistor 1.8 Meg. ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-14	Resistor 20 K ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-15	Resistor 100 K ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-16	Resistor, Zero Ω		
R-18	Resistor, Zero Ω		
R-20	Resistor, Zero Ω		
R-22	Resistor, Zero Ω		
R-24	Resistor, Zero Ω		
R-26	Resistor, Zero Ω		

Part No.	Description	Source	Price
R-28	Resistor, Zero Ω		
R-30	Resistor, 50 K ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-32	Resistor, Zero Ω		
R-34	Resistor, 45 K, ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-35	Resistor, Zero Ω		
R-37	Resistor, 500 K ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-38	Resistor , Zero Ω		
R-40	Resistor, 1.25 Meg. ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-41	Resistor, Zero Ω		
R-43	Resistor, 1.20 Meg. ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-44	Resistor, 1.50 Meg. ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-46	Resistor, Zero Ω		
R-47	Resistor, 430 K, ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-49	Resistor, 91K ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-50	Resistor, 220 K ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$		.65

Part No.	Description	Source	Price
R-52	Resistor, 50 K ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-53	Resistor, 33K ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-55	Resistor, 10 K ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-57	Resistor, 1.0 Meg. ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-58	Resistor, 2.0 Meg. ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-59	Resistor, 1.0 Meg. ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-60	Resistor, 10 Meg. ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.72
R-61	Resistor, 10 Meg. ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.72
R-63	Resistor, 80 K ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-64	Resistor, 50 K ± 1% Aerovox Carbofilm deposited carbon CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-65	Resistor, 10 Meg. ± 1% Aerovox Carbofilm deposited carbon CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.72
R-66	Resistor, 10 Meg. ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.72

Part No.	Description	Source	Price
R-68	Resistor, 80 K ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-69	Resistor, 50 K ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-70	Resistor, 50 K ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-71	Resistor, 50 K ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-73	Resistor, 10 K ± 1% Aerovox Carbofilm deposited carbon, CP 1	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.77
R-74	Resistor, 10 K ± 1% Aerovox Carbofilm deposited carbon, CP 1	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.77
R-75	Resistor, 100 K ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-76	Resistor, 1 Meg. ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-77	Resistor, 4.2 Meg. ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.89
R-81	Resistor, 820 K ± 1% Aerovox Carbofilm deposited carbon CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-82	Resistor, 220K ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-83	Resistor, 220 K ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65

Part No.	Description	Source	Price
R-84	Resistor, 10 K ± 1% Aerovox Carbofilm deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-85	Resistor, 1 Meg. ± 1% Aerovox Carbon deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-86	Resistor, 1.2 Meg. ± 1% Aerovox Carbon deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-87	Resistor, 1 Meg. ± 1% Aerovox Carbon deposited carbon, CP $\frac{1}{2}$	Aerovox Corp. 740 Belleville St. New Bedford, Mass.	.65
R-1	Potentiometers, Type AB Ohmite, 3.5 Meg	Ohmite Co. 3601 Howard St. Stokie, Ill	1.76
R-3	Potentiometer, Type AB Ohmite, 2.5 Meg.	Ohmite Co.	1.76
R-5	Potentiometer, Type AB Ohmite, 1.0 Meg.	Ohmite Co.	1.76
R-7	Potentiometer, Type AB Ohmite, 5.0 Meg.	Ohmite Co.	1.76
R-9	Potentiometer, Type AB Ohmite, 2.5 Meg.	Ohmite Co.	1.76
R-11	Potentiometer, Type AB Ohmite, 500 K	Ohmite Co.	1.76
R-13	Potentiometer, Type AB Ohmite, 20 K	Ohmite Co.	1.76
R-17	Potentiometer, Type AB Ohmite, 2.5 K	Ohmite Co.	1.76
R-19	Potentiometer, Type AB Ohmite, 2.5 K	Ohmite Co.	1.76
R-21	Potentiometer, Type AB Ohmite, 7.5 K	Ohmite Co.	1.76

Part No.	Description	Source	Price
R-23	Potentiometer, Type AB Ohmite, 7.5K, CLU 7521	Ohmite Co. 3601 Howard St. Stokie, Ill.	1.76
R-25	Potentiometer, Type AB Ohmite, 25K, CLU 2531	Ohmite Co.	1.76
R-27	Potentiometer, Type AB Ohmite, 25 K, CLU 2531	Ohmite Co.	1.76
R-29	Potentiometer, Type AB Ohmite, 150 K, CLU 1541	Ohmite Co.	1.76
R-31	Potentiometer, Type AB Ohmite, 150K, CLU 1541	Ohmite Co.	1.76
R-33	Potentiometer, Type AB Ohmite, 50 K, CLU 5031	Ohmite Co.	1.33
R-36	Potentiometer, Type AB Ohmite, 100 K, CLU 1041	Ohmite Co.	1.76
R-39	Potentiometer, Type AB Ohmite, 100 K, CLU 1041	Ohmite Co.	1.76
R-42	Potentiometer, Type AB Ohmite, 0.75 Meg. CLU 7542	Ohmite Co.	1.76
R-45	Potentiometer, Type AB Ohmite, 350 K, CLU 3541	Ohmite Co.	1.76
R-48	Potentiometer, Type AB Ohmite, 35 K, CLU 3531	Ohmite Co.	1.76
R-51	Potentiometer, Type AB Ohmite, 25 K, CLU 2531	Ohmite Co.	1.76
R-54	Potentiometer, Type AB Ohmite, 5 K, CLU 5021	Ohmite Co.	1.76
R-56	Potentiometer, Type AB Ohmite, 25 K, CLU 2531	Ohmite Co.	1.76
R-62	Potentiometer, Type AB Ohmite, 50 K, CLU 5031	Ohmite Co.	1.33
R-67	Potentiometer, Type AB Ohmite, 50 K, CLU 5031	Ohmite Co.	1.33

Part No.	Description	Source	Price
R-72	Potentiometer, Type AB Ohmite, 50 K, CLU 5031	Ohmite Co. 3601 Howard St. Stokie, Ill.	1.33
R-75	Potentiometer, Type AB Ohmite, 2.5 K, CLU 2521	Ohmite Co.	1.76
R-78	Potentiometer, Type AB Ohmite, 5 K, CLU 5021	Ohmite Co.	1.76
R-79	Potentiometer, Type AB Ohmite, 50 K, CLU 5031	Ohmite Co.	1.33
R-80	Potentiometer, Type AB Ohmite, 1 Meg, CLU 1052	Ohmite Co.	1.76
C-1	C-1 Capacitors, 10 μfd 200 WVDC D2-2-10,000	Film Capacitors, Inc.	6.26
C-2	C-2 Capacitors, 1 μfd 200 WVDC D3-2-1000	Film Capacitors, Inc.	1.87
A	Relay, 110 VDC, Type 3PDT, 10 KΩ. (1 each) KRP14D	Potter & Brumfield Princeton, Ind.	6.48
B	Relay, 24 VDC, Type 3PDT, 573 Ω (2 each) KRP14D	Potter & Brumfield	6.00
C	Relay, 110 VDC, Type 3PDT, 10 KΩ (1 each) KRP14D	Potter & Brumfield	6.48
D	Relay, 24 VDC, Type 3PDT, 472 Ω (2 each) KRP14D	Potter & Brumfield	6.00
E	Relay, 24 VDC, Type 3PDT, 472 Ω (1 each) KRP14D	Potter & Brumfield	6.00
R	Relay, 24 VDC, Type 3PDT, 472 Ω (3 each) KRP14D	Potter & Brumfield	6.00
	11 each 11 contact sockets, 11 RB	Cinch-Jones Co. 1026 S Homan Ave. Chicago, Ill.	.26
	12 each retaining rings No. 1018	Cinch- Jones	.04

Part No.	Description	Source	Price
	1 each Octal socket No. 821	Cinch-Jones Co. 1026 S. Homan Ave. Chicago, Ill.	.18
D_1 - D_8	1N458 Transitron Diode	Transitron Electronic Corp., Boston, Mass.	3.20
D_9 - D_{14}	1N459 Transitron Diode	Transitron	3.45
Console	1 each Multi-Section Rotary Switch No. 1331L	P. R. Mallory Co. 3029 E. Washington St. Indianapolis, Ind.	2.23
Console	1 each Multi-section Rotary switch, No. 1366L	P. R. Mallory Co.	1.06
Console	1 Each, Type 1454-A Decade Voltage Divider,	General Radio Co. West Concord, Mass.	150.00
Console	1 each Power Supply No. 3106-R	Donner Scientific Co.	335.00
Console	2 each Dual Amplifier No. 3101	Donner Scientific Co.	460.00
Console	2 each No. J-0086 Amplifier Connector	Donner Scientific Co.	2.50
Console	PN-12 Panel	Emcor Ingersol B-W Corp. Products Division 630 Congden Ave. Elgin, Ill.	5.00
Console	FR-175A Frame	Emcor Ingersoll B-W Corp.	76.55
Console	SP-175A RH Side Panel	Emcor Ingersoll B-W Corp.	20.30
Console	SP-175A LH Side Panel	Emcor Ingersoll B-W Corp.	20.30
Console	DO-42B-LV-LH Door	Emcor Ingersoll B-W Corp.	27.15
Console	DO-42B-LV-RH Door	Emcor Ingersoll B-W Corp.	27.15
Console	PN-15PA Top Panel	Emcor Ingersol B-W Corp.	6.85
Console	PN-17 Panel	Emcor Ingersol B-W Corp.	5.30
Console	PN-15 Panel	Emcor Ingersol B-W Corp.	4.95
Console	DR-7A-25 Drawer	Emcor Ingersol B-W Corp.	25.80

Part No.	Description	Source	Price
Console	DR-10A-25 Drawer	Emcor Ingersoll B-W Corp. Products Division 630 Congdon Ave. Elgin, Ill.	28.90
Console	PN-3 Panel	Emcor Ingersoll B-W Corp.	2.10
Console	FR-61A-25 Frame	Emcor Ingersoll B-W Corp.	33.40
Console	C6S-25A Chassis Guides and supports	Emcor Ingersoll B-W Corp.	10.30
Console	PN-10F Formica Panel	Emcor Ingersoll B-W Corp.	4.85
Console	SP-61A Side Panel	Emcor Ingersoll B-W Corp.	3.55
E. Recorder			
	Oscillograph, Visicorder Model 906 Bl, 14 Channel Direct writing, with (a) 5-25-50-100 mm/sec drive system with following accessories (b) Grid line system calibrated in millimeters (c) Standard collector lens (d) Recording intensity control (e) Trace identifier (f) Timing unit (.01, 0.1, 1 Sec) (g) Record takeup and latensifier (h) 2 Each, M3300T timing galvanometers (i) M40-120 galvanometer (j) M40-350 galvanometer (k) Spare recording lamp No. 100179	Minneapolis-Honeywell	4002.55

Part No.	Description	Source	Price
	(l) 3 rolls-Visicorder recording paper No. 301151		
	(m) Cable, timing unit to 906-B-1 recorder		